NOTES ON COMPARATIVE HISTOLOGY OF BLOOD AND MUSCLE.

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The difficulty of basing general histology on books and discussions of human histology must have presented itself to anyone who has attempted to do it. Since almost all the standard reference books on the subject are written from a medical point of view for medical students the gap between standard books and the materials used becomes quite wide. Even if any mammal other than man is made the object of study, there is trouble since many of the tissues of the cat and rabbit, for instance, vary widely from the same tissues in man, while if any of the lower forms are used still greater differences are present. Compound tissues, in particular, differ, many layers well recognised in human tissues being absent or poorly developed. Many of the elementary tissues also are markedly different in the various animal forms. These points led me to examine some of the tissues of a few of our common animals to find the differences present, and if possible some explanation of them.

The animals chosen were the rabbit, cat, pigeon, turtle, snake, frog (*Rana viridis*), *Amblystoma*, *Cryptobranchus Necturus*, and also, to a slight extent, Amia a Ganoid fish, and *Protopterus* a Dipnoan.

The results are necessarily limited and somewhat incomplete, only two tissues being examined thoroughly.

Blood and Striped Muscle.—Some others are partly worked out, but not fully enough for discussion.

Blood, a tissue in form, if not in function, has received a very large share of attention, greatly owing to its medical and legal importance. Interest has always been centered on the size and number of the red corpuscles, a structure, so far as known, peculiar to vertebrates.

The corpuscles of all animals fall into two natural groups, those with nuclei and those without; these almost agree, with a division on the basis of shape, oval and circular, with but one exception, on each side. All mammals, so far as known, possess normally non-nucleated, biconcave, circular red corpuscles, with the exception of the camel tribe, which has oval cells. All other vertebrates—birds, reptiles, amphibians and fishes—possess nucleated oval corpuscles, with also one exception; the lampreys (*cyclostomes*) have circular nucleated corpuscles.

I have either made or collected from various sources measurements of the red blood corpuscles of as many forms in these classes as possible, with the following results placed in the form of a table.

Drawings were made from fresh preparations of *Amia*, snake, pigeon, frog, *Cryptobranchus*, *Necturus*, lamprey and man. The drawing of *Amphiuma* was made from preserved material. (Plate I.)

SIZES OF CORPUSCLES.

	Oval.		Authority.	Circular.		
	L.	B.				
FISHES :	μ	μ			μ	
Teleost :				Man	7.5	E. J. C.
Carp	15	9	Brass.	Mammals . . .	6.5	
Teleosts in general	18.1	11.4	Frey.	Lamprey Eel . .	12.6	E. J. C.
Ganoid :				Cyclostomes .	11.3	
Sturgeon	13	10	Welcker.			
Amia .	11.6	8.6	E. J. C.			
Elasmobranchii :						
Ray and shark .	28.5	. . .	Frey.			
	22.6	. . .				
Dipnoan :						
Lepidosiren . . .	41	29	Welcker.			
AMPHIBIANS :						
Scaly	18.2	15	Frey.			
Frog	23.2	16.5	E. J. C.			
Toad	24	16	E. J. C.			
Triton	25	16	Brass.			
	37.5	. . .	Frey.			
Megalobatrachus . .	47	33	Brass.			
Cryptobranchus . .	48.7	29.2	E. J. C.			
Necturus	58.4	31.1	E. J. C.			
Proteus	58	35	Brass.			
Siren	59	30	Vailians.			
Amphiuma	75	45	E. J. C.			
REPTILES :						
Turtle	15	6	Brass.			
Snake	15.7	12.9	E. J. C.			
Lizard	16	10	Brass.			
	13	10				
Alligator	20	7	E. J. C.			
BIRDS :						
Fowl	12	7	Brass.			
Pigeon	12	7	E. J. C.			
MAMMAL :						
Camel	8	4	. . . . .			

These figures are very significant and suggestive. Variation ranges from 6 μ. to 75 μ. Among the heterogeneous class "fishes" there is marked difference. *Cyclostomes* have circular cells, quite small, 12.6 μ. in diameter. In Teleosts and Ganoids (carp and *Amia*), two of the more specialised groups, the size is about equal, 15 μ. x 9 μ. and 11 μ. x 6 μ. The size increases in Elasmobranchs, represented by the ray and shark, it is 22.6—28.5, (short diameter not given). The most generalised fish, the Dipnoan or lung-fish, possesses still larger corpuscles, 41 μ. x 29 μ. Here in this series specialisation is accompanied by decrease in size. (Plate II., Figs. 10–14) Again, among the Amphibians, the Cecilians, limbless, tailless, scaly, worm-like animals, the corpuscles are small, 18.3 μ. x 15 μ., nearly circular. Frogs and toads, very specialised in many respects, have corpuscles 22 μ. x 16 μ., approximately. *Triton* gives cells 25 x 16 or 32.5 x — both sizes are given, but there is no basis to judge which figures are correct. *Megalobatrachus*, the great Japanese salamander, has corpuscles 47 μ. x 33 μ *Cryptobranchus*, the American cousin of this foreigner, agrees in size of these cells, 48.7 μ. x 29.2 μ. These are two air-breathing, tailed Amphibians, far more generalised in gross structure than the frogs and toads. The three following ones, *Necturus*, *Proteus*, the blind cave form of Europe, and *Siren*, all very generalised forms, make a group together, their corpuscles measure 58.4 μ. x 31.1 μ., 58 μ x 35 μ., 59 μ. x. 30 μ. Last in this list is amphiuma, an air-breathing form, but possessing the largest corpuscles known, 75 μ. x 45 μ. Thus again among the Amphibians there is a regular decrease in size accompanying an increase in specialisation. (Plate II., Figs. 15–20) But few forms of reptiles can be discussed, and there is less variation in those examined. Turtle shows corpuscles 15 μ. x 6 μ.; snake, 15 μ. x 12.9 μ.; lizard, 15 μ. x 10 μ.; alligator, 20 x 7 (Plate II., Figs. 21, 22). All are much smaller than those of the Amphibians, agreeing more with the Teleosts and ganoids. In the birds there is a still further decrease in size, the fowl and pigeon agreeing in corpuscles, 12 μ. x 7 μ. Finally, among mammals the circular corpuscles vary from 2 5 μ. to 9 μ., averaging 6.5. The only other circular cells known are the nucleated corpuscles of the lamprey and hag fishes, which are larger, as shown in the table ; they average 12.6 μ. in diameter.

In this whole series there is a gradual decrease in size from the generalised to the specialised forms, not only in the different members of the classes, but also in the different classes themselves. At each end of the table are specialised forms—not equally so, but both far from primitive—modern fishes and birds and mammals. Between them are less specialised forms, and among these are found some of the largest corpuscles known. None of them are of greater interest than the amphibia, a class acknowledged to contain most widely varying forms, some highly specialised and others exceedingly generalised. The worm-like, degenerate Cecilians have small, nearly circular corpuscles (Plate II., Fig. 15), and from this there is a steadily increasing series, culminating in the fairly gigantic cells of *Amphiuma*. Passing away from amphibians, on the other side, the size again decreases, and, finally, in the mammals are some of the smallest cells known. There is one point more of interest to notice in these cells. It is, perhaps, only an accidental coincidence, but the cells of all the presumably degenerate forms examined are approximately circular, if not completely so. The lamprey 12.6 μ. in diameter; *Cecilian*, 18 μ. x 15 μ.; snake, 16 μ. x 13 μ.

There is another striking change in this series besides decrease in size. The normal absence of the nucleus from mammalian red corpuscles and the presence of it in all other red corpuscles is well known. Can the loss of this part be explained, a part so essential to ordinary cells? Consideration of the function of the red cell will assist in answering this question. It is no longer a typical cell; its protoplasm is highly specialised for one purpose, to hold hemaglobin (this substance makes 90 per cent. of the corpuscle), which in turn serves to take up, during the circulation of the blood through the lungs or skin, the oxygen essential for maintaining life. In all reserve cells the nucleus is the organ of division; through its means two cells arise from one. In other cells it may assume some other function. The red blood corpuscle with its protoplasm saturated with hemaglobin has become highly specialised for one function, to carry oxygen; the more hemaglobin carried, the more efficient is the cell in its work. The original use of the nucleus is lost, the work of the cytoplasm prevents it from acquiring a secondary use, it becomes a rudimentary cell organ, decreases in size and, when specialisation is pushed to the extreme, disappears altogether. In the most highly developed animals, the mammals, in which activity and power are greatest and most constant, and the necessity for rapid supply of oxygen to the tissues most urgent, the red corpuscles are reduced to a mass of protoplasm saturated with hemaglobin, a voracious oxygen eater. The nucleus is gone, it only occupied precious space, which is far better filled with the oxygen carrier. What else could be expected than this loss when the oxygen carrier is at such a premium? For loss it is, despite those who maintain the presence of a nucleus in mammalian red blood corpuscles. The advantage of the increased possibility far outweighs any use this rudimentary organ may have had, hence its loss. This disappearance is gradual, large in amphibians, the nucleus is reduced to a mere line in birds (Plate I., Fig. 3) to vanish entirely in mammals normally.

The gradual decrease in size of the cells is very readily explained on the same principle. Chemical exchange takes place far more rapidly and completely in many small masses than in a few large ones. A consequent decrease in size attended by a great increase in number takes place, resulting in a very large number, 5,000,000 per cu. mm. of 7 μ. bodies (man), against 56,000 of 58 μ. bodies (*Necturus*). The hemaglobin is increased in amount by loss of nucleus and rendered far more accessible by decrease in size of these cells. These advantages gained show reason enough for this law of decrease in size and the gradual loss of the nucleus in the adult corpuscle of mammals. Perhaps a series of careful observations on the blood of mammals and birds might show connecting links between the non-nucleated and nucleated corpuscles.

Here is a general law of decrease in size attending specialisation established for one tissue. Is this a general law applicable to all tissues? Blood is a tissue of a very special nature, and another possessing at least many similar qualifications is *striped muscle.*

MUSCLE.

The ultimate structure of striped, or, as it is often called, voluntary muscle, is in many points even yet under discussion, many complicated theories being suggested as possible explanations of the appearances found under the microscope. These, however, are not the points to be discussed, but rather some others usually only incidentally noted, yet from a comparative standpoint of significance.

It is well known that the nuclei of the striped muscle fiber of mammals lie just under the sarcolemma or limiting membrane of the muscle fiber. In the frog the nuclei, as shown in transection, are scattered through the contractile substance of the fiber. The constancy of these respective positions shows them not to be merely accidental, but characteristic of each animal. Other points also appear of greater or less importance : size and shape of fiber ; number, shape and size of nuclei ; arrangement of fibers in fascicles and the structure of the sarcous substance as apparent from longitudinal and transections.

The following animals have been used; in all cases possible animals of the same physiological value were chosen ; they were treated subsequently by the same processes in all possible cases : lamprey, *Amia*, *Protopterus*, frog, *Amblystoma*, *Cryptobranchus*, *Necturus*, turtle, snake, pigeon and cat. The results are arranged in the following tabulated form :

Animal.	Av'rage Size of Fiber.	Range in Size.	No. of Nuclei.	Location of Nuclei.	Size of Nuclei.	Cohn-heim's areas.	Coarse or Fine in Section.	
Cyclostome :								
Lamprey	10 μ	6 12 μ	1-2	Inside usually,	Small	Present,	Medium	Being small nuclei came to edge more often.
Ganoid :								
Amia	18 9 μ	15-21	1-2	Inside	Medium	None	Fine	From esophagus.
Dipnoan :								
Protopterus	35 μ	21-45	1 2	Edge	Large	Present,	Fine.	
Amphibians :								
Frog	45	30 54	2-5	Inside	Small	Present,	Fine.	
Amblystoma	42.3	*30-57	2-3	Inside	Fairly large	Absent,	Coarse	Has dotted coarse effect by having few fibrils in a mass.
Cryptobranchus	78.6	6 105	2-3	Inside	Quite large	Absent,	Coarse, homogeneous	
Necturus	88.5	60-131	2-3	Inside	Very large	Absent,	Coarse, homogeneous	Nuclei 45x9 μ.
Turtle	54	36 66	2-4	Inside	Medium	Absent,	Coarse.	
Snake	97.8	75-155	3-5	Inside	Small and oval	Present,	Coarse	Dotted like Amblystoma.
	89.7	60-144	25-35	Inside	Small and round,	Present.	Very fine	Very fine and dense.
Pigeon	20.7	15-27	2-3	Edge	Small	Present, Absent,	Fine Coarse.	Fine and coarse fibers.
Mammal	21.1	15-30	1-2	Edge	Small	Present,	Fine.	

* One fiber 87 μ.

These facts do not run quite as smoothly as in the first case.

The line between the muscle fibers having nuclei imbedded in the sarcous substance and those having them at the edge, is drawn between the cold and warm-blooded animals—fishes, amphibians and reptiles—against birds and mammals, with one exception, the Dipnoan (*Protopterus*), in which the nuclei are at the edge as in birds and mammals ; they are much larger, however, than in the latter fibers. The number of nuclei visible from a transection is, on the whole, the same, averaging 2-3, again with one exception, to be discussed later.

The terms coarse and fine have been used to describe the appearance of these fibers in transection. The explanation of this appearance is probably that the fibrils forming the fibers vary in size in different animals. A transection of a fiber involves transections of its constituent fibrils. If these are small the fiber looks fine-grained (Plate III., Figs. 29, 32 ; Plate V., Fig. 43) ; if large, a coarse effect results (Plate III., Fig. 30 ; Plate IV., Figs. 36, 38, 39). In longisections there is also a noticeable difference. In longitudinal view of ordinary striped mammalian muscle the cross-stripes are usually far more prominent than any others. In some of the more generalised forms the cross-stripes become merged into very much emphasised longitudinal striations (Plate III., Fig. 33 ; Plate IV., Figs. 35, 37). This difference can be explained by the varying size of the fibrils ; if they are large their size gives the effect of longitudinal striations. In the largest these become more strongly marked than the characteristic cross-stripes.

One animal presents some very peculiar conditions. In the snake there are two kinds of fibers shown in transection ; one is typical, coarse-grained, with 3-4 oval nuclei imbedded in the sarcous substance ; the other is very dense, close, showing long cracks and lines across the surface, dividing it into irregular areas. The second marked difference between this fiber and the typical one is in the number of nuclei. Instead of 3-5 in each section there are as many as 25-35, an enormous increase. It appears from this view as if there were two distinct kinds of fibers. Examination of a longisection at once shows this to be untrue. These two apparently distinct structures belong to the same fiber ; they pass abruptly into each other. The typical muscle is faintly cross-striped and rather clearly longitudinally striated. It has long oval nuclei scattered here and there through it. Suddenly this structure stops, the fiber becomes slightly larger in diameter, it loses all cross-stripes and nearly all longitudinal markings. The sarcous substance is dense and compact. Instead of a few oval nuclei there are a large number of small round ones scattered through it (Plate V., Fig. 41). So far as I know this is only found in snake muscle. Isolated material should be examined in order to fully investigate this peculiar condition ; at present all that I can suggest is that it is some peculiar ending of the fibers. In the pigeon there is a slight difference also shown in cross-section between the muscle fibers ; some appear coarse and others very dense, but in longisection there is no appreciable distinction to be made.

So here again is the same law, large fibrils in the generalised forms, small ones in the specialised. This is fairly consistent, the snake and dipnoan being the only exceptions.

The presence or absence of the so-called Cohnheim areas is also significant. These are divisions of the fibers (visible in transection) by irregular lines passing over the surface, probably caused by the massing of the fibrils into bundles. In specialised forms (lamprey, frog, bird, cat, Figs. 26, 27, 32, 42, 43) these areas are present, in generalised forms they are absent (Figs. 30, 34, 36, 38). The Dipnoan is a noteworthy exception to this rule, as the position of the nuclei also shows.

The question of size must necessarily be approached with caution. In form, muscle fibers are not so independent of physiological changes as are red blood corpuscles. A fully developed active muscle fiber is well known to be larger than an ill-developed one. Hence differences are to be expected between animals with good and those with but slightly developed muscular systems. This point must be borne in mind; also another, that all animals are not equally active at all times of the year, and that there may be a difference in size of fibers under the different physiological conditions to which they are subjected.

There is a great range in size among fibers examined, from 10 μ. to 97 μ. The smallest are those of lamprey, a relatively inactive animal, but it also has its other tissue elements small. The *Amia* and Dipnoan follow in this series in size.

The frog, strongly muscular when active, has fibers 45 μ. in diameter. *Amblystoma*, *Cryptobranchus*, *Necturus*, follow in gradually increasing sizes. Turtle is smaller, snake, an exception, larger, but bird and mammal are both small.

This series, in spite of variations, coincides fairly well with the series of blood corpuscles in all but one or two respects, which can be explained in part by the interference of other agents. In spite of increase in muscular power there is a gradual decrease in size from the generalised to specialised. No one would compare favorably the slow, sluggish *Cryptobranchus* or *Necturus* with birds or mammals in regard to muscular power, yet the former have far the largest fibers, which ought to indicate muscular activity, if size is the sole criterion. Very small size in *Cyclostomes* may be caused by specialisation and by lack of muscular activity. The one striking exception in size, the snake fibers, may perhaps be accounted for by its exceptional mode of locomotion. The difficulty of moving a limbless body over the ground is very great, and this demand for great force is satisfied by great increase in size of fibers. The peculiar second kind, possibly special endings, cannot at present be discussed. The other possible explanation in size lies in degeneration, or reversion rather, back to a primitive condition.

The change of position and decrease in size of the nuclei is perhaps easier to explain. In its physiological action the force is exerted in a lengthwise direction through each fiber, ultimately by contraction of fibers. The presence of nuclei, non-contractile masses, must prevent, to a considerable degree, the fibrils about them from producing the full effect of their contraction, since they must pull obliquely around the nuclei. Decrease in size of nuclei assists somewhat in preventing this waste by straightening the pull somewhat, but by pushing the interfering bodies to the wall, or, in other words, to the sarcolemma, completely obviates the difficulty ; the fibrils can exert their full power and yet the nuclei remain to perform their function, whatever it may be. This is effected in the two highest classes—birds and mammals ; in them muscular activity is at a premium in force and endurance. The decrease in size of the fibrils is also in favor of action ; the same number of fibrils can be crowded into a smaller space and so more fibrils be present and a far more efficient nerve supply and blood supply. Owing to the small fibers the exchange between blood and tissue must be more rapid with small than large fibers.

While considering for a moment the results of these observations it may be objected to that blood is not a good tissue for basing an argument of this kind on. It is so intangible, always changing its chemical nature, always moving from place to place. But the very singleness of its aim renders it one of the best. Its function is the same for all animals, its movements practically the same; through this series the development of an essential mechanism can be traced, until it finally attains perfection in the highest forms of animal life, the mammals. Muscle is also a very specialised tissue, and is instructive in showing the mode of development along an essentially different line.

Briefly summing up we find the results, on the whole, harmonious ; a general law can be deduced which applies to the main animal tissues. The more generalised the animal the larger the tissue elements ; the more highly specialised the smaller are the elements. This is a very natural law ;

all growth and change in body depends on growth and change in cells forming it. It is but logical to expect such profound changes to show their influence on these important agents. Exceptions to it are found, of course, "no rule without an exception" says the old adage. Such should, however, be expected since the evolution of these elementary tissues is conditioned by the same laws as that of the animal as a whole. It is a commonly accepted fact that a form may be highly specialised in some lines and yet possess one or more very generalised structures. So an animal may, as a whole, be generalised in its tissues as Dipnoan (*Protopterus*), yet exhibit some one specialised tissue, for instance, its muscle marking it at once from the other tissues.

This same line of treatment can be equally well applied to any other tissues, simple or compound, but at present I have not sufficiently examined or studied them to discuss the results, though an interesting field of work is opened by this method of treating the elementary structures of animal bodies by the same methods as have long been used in comparative anatomy.

PLATE I.

Red blood corpuscles (drawn from fresh material). Except figure 7.

Fig. 1. Amia—Ganoid.
Fig. 2. Snake.
Fig. 3. Pigeon.
Fig. 4. Frog.
Fig. 5. Cryptobranchus.
Fig 6. Necturus.
Fig. 7. Amphiuma.
Fig. 8. Lamprey (petromyzon).
Fig. 9. Human.

PLATE I.

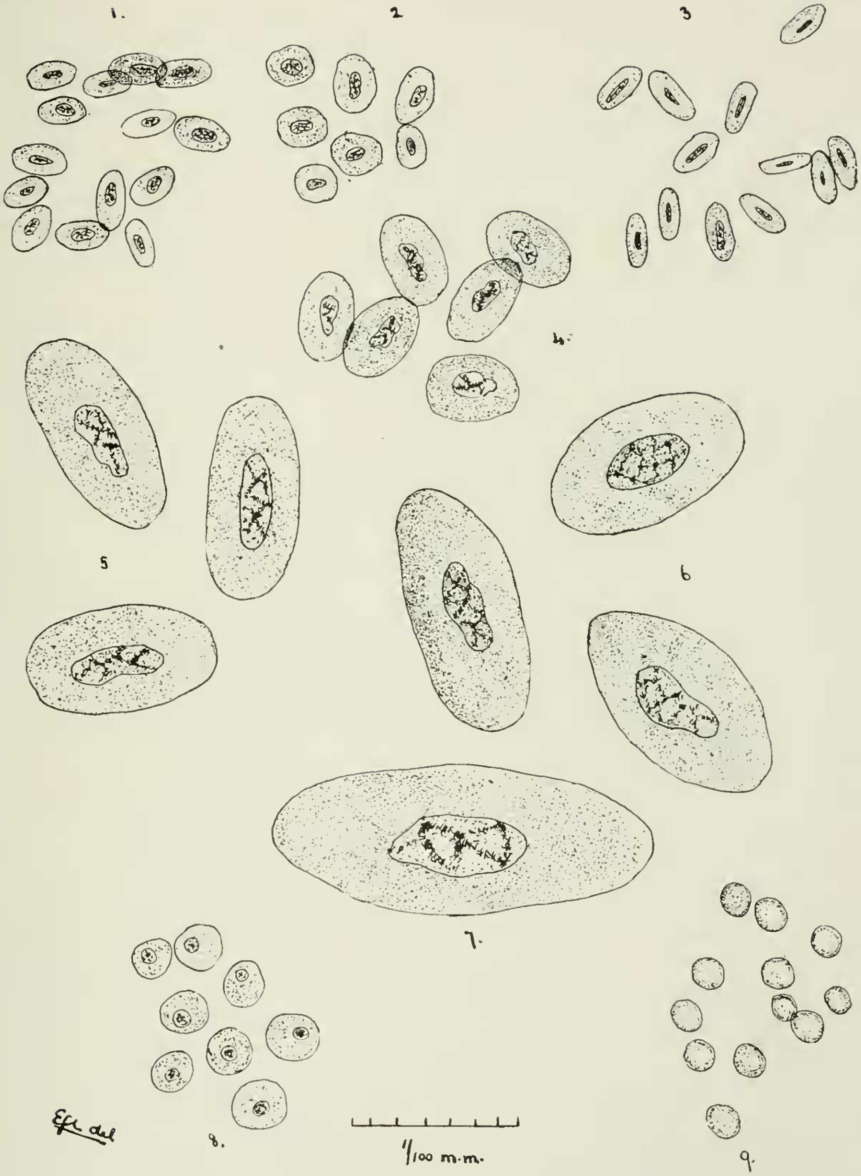

PLATE II.

Diagrams of blood corpuscles.

Fig. 10. Lamprey (cyclostome).
Fig. 11. Carp (teleost).
Fig. 12. Amia (ganoid).
Fig. 13. Sturgeon (elasmobranch).
Fig. 14. Protopterus (dipnoan).
Fig. 15. Cecilian (amphibian).
Fig 16. Frog (amphibian).
Fig. 17. Salamander (amphibian).
Fig. 18. Cryptobranchus (amphibian).
Fig. 19. Necturus (amphibian).
Fig. 20. Amphiuma (amphibian).
Fig. 21. Turtle (reptile).
Fig. 22. Snake (reptile).
Fig. 23. Pigeon (bird).
Fig. 24 Camel (mammal).
Fig 25. Man (mammal).

Some of these are reconstructed from measurements.

PLATE II.

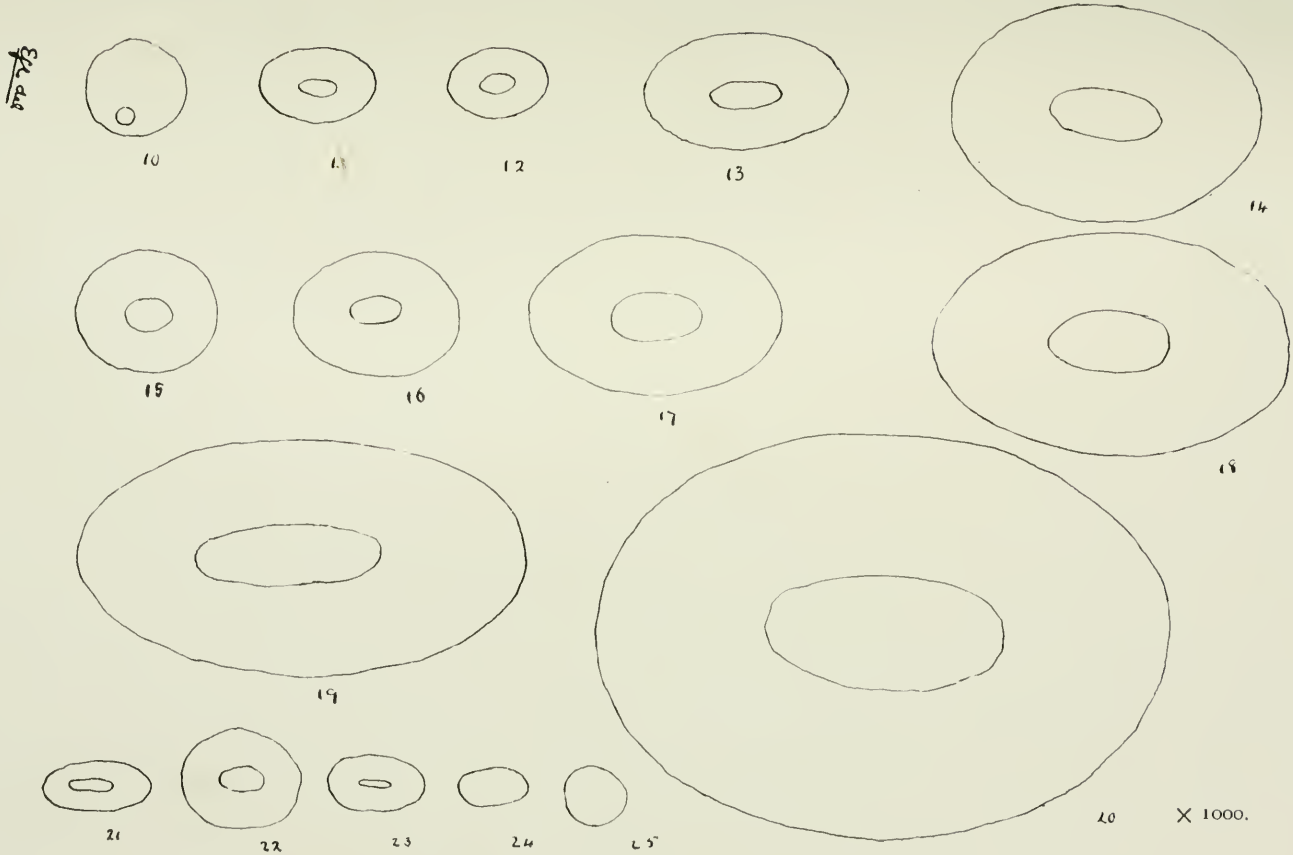

PLATE III.

Muscle.—Transections and longisections of striped muscle fibers.

Fig. 26. Lamprey. Body muscle.
Fig. 27. Amia. Esophagus.
Fig. 28. Protopterus. Longisection of body muscle.
Fig. 29. Protopterus. Transection.
Fig. 30. Amblystoma. Transection.
Fig. 31. Frog. Longisection (Sartorius).
Fig. 32. Frog. Transections.
Fig. 33. Amblystoma. Longisection.

Longitudinal striations shown in Amblystoma and are absent in Protopterus and frog.